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ABSTRACT

In this paper, the results of theoretical analyses related to the evaluation of site effects in Tehran city, the capital of Iran, are presented. To evaluate the response of site, recorded bedrock motions in BHRC (Building and Housing Research Center) acceleration stations at Tehran city were used as bedrock input motion. These motions were recorded during Firozabad-Kojour (2004) earthquake (Ms=6.4), which occurred near Tehran city. Equivalent linear analysis was performed to evaluate the seismic response of each selected geotechnical and geophysical profile subjected to the scaled 475-year bedrock input motion. The results are presented in terms of site response spectrum and site amplification factor, computed in the period ranges 0.1- 0.5 and 0.1- 2.5 s. The estimated site response spectra were compared with the suggested one in Iranian Code (Standard No. 2800). This comparison reveals that there are acceptable trend between the estimated response spectra and Iranian Code. The values of amplification factor in ranges of period 0.1–0.5s and 0.1–2.5 s can also be considered in designing typical and generic buildings of the area.

INTRODUCTION

During an earthquake local site conditions can significantly influence on the important characteristics of incoming seismic waves. The extent of their influence depends on the geometry and material properties of the subsurface layers. The nature of local site effects can be estimated in several ways: by simple, theoretical ground response analysis using geotechnical and geophysical information; by empirical methods using measurements of the actual surface and subsurface ground motions at the same site; and by measurements of ground surface motions from site with similar subsurface conditions (Kramer, 1996).

Tehran city, the capital of Iran, is a densely populated city with a large building inventory and high rate of construction, located in an area of high seismic activity. For these reasons, the study of potential site effects in Tehran is important. The area of study is located within latitudes 35°34′ N and 35°50′ N and longitudes 51°04′ E and 51°36′ E, including the Tehran metropolitan area (Fig. 1). According to geotechnical and geophysical data, site conditions in most parts of city are categorized as C class (based on class assigned way by NEHRP), which are encompassed most important facilities and large building inventories and it seems necessary to clarify the important characteristics of C class sites in Tehran city. In this study by using bedrock input motions, geotechnical, and geophysical properties of soils at different sites, the response spectrum and amplification factor for selected sites, which are categorized as C class, are calculated. For this purpose, the following steps were taken in site effects assessment:

- Processing geophysical data and estimating basic seismic parameters including depth to seismic bedrock, site predominant period, and site classification (Fig. 2);
- Estimating the scaled acceleration time history based on recorded bedrock motions;
- Extracting appropriate sites with complete geotechnical and geophysical data and Preparing their representative profiles for equivalent-linear site response analysis (Fig. 2);
- Estimating site response spectrum and site amplification factor for selected sites (Fig. 2).

STUDY AREA CHARACTERISTICS

Seismicity of Tehran

Tehran, which is located in a very high seismic zone at the foot of the Alborz Mountains, is surrounded by several active

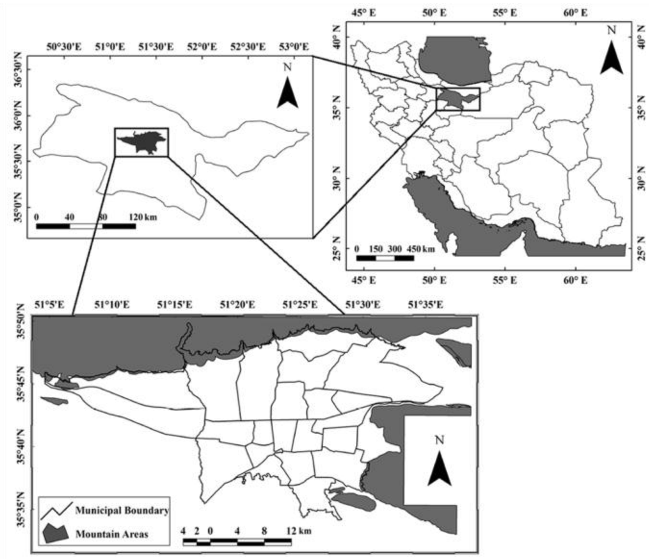


Fig. 1. Location of study area.

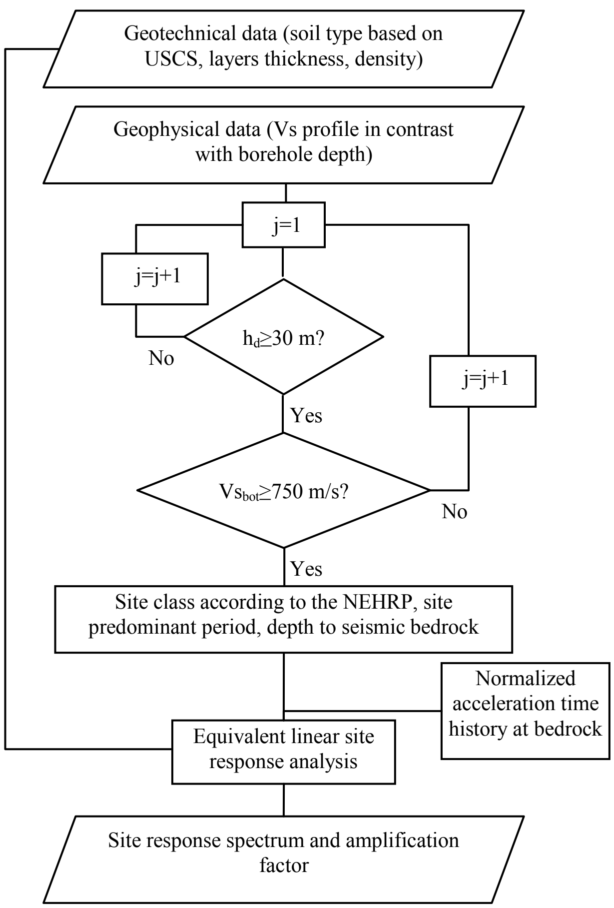


Fig. 2. Flowchart of data processing.

faults. The most important faults outside the city are the Mosha and the North Tehran having left-lateral strike-slip movements with a small reverse component, and the North Ray, the South Ray, the Garmsar, and the Kahrizak faults having reverse mechanism (Hessami et al, 2003). It should be noted that small faults are widespread throughout the city and reactivation of major faults may cause movement along the smaller faults. Despite the limited available seismic data, a review of historical earthquakes in Tehran indicates that the region is highly vulnerable to seismic activity and has experienced several destructive earthquakes. The characteristics and distribution of historical and instrumental earthquakes with Ms≥5.5 around the city (r≤250 km) are shown in Table 1 and Fig. 3, respectively (Ambraseys et al, 1982). The occurrence of about six earthquakes with magnitude greater than 6 during the 20th century in Tehran region indicates activity of the faults. Recently there have been no strong events near Tehran but many instrumental earthquakes greater than Ms=5.5 have occurred in vicinity. Some instrumental events around Tehran (r≤150 km) are the 1957 Sangchal, the 1962 Ipak, the 1990 Rudbar, the 2004 Firozabad-Kojour, and the 2007 Kahak-Qom earthquakes.

Table 1. Historical and instrumental earthquakes around Tehran with r≤250 and Ms≥5.5

No.	Year	Month	Day	Lat.	Long.	Ms	R(km)
1	4thBC			35.50	51.80	7.6	50.00
2	743			35.50	52.20	7.2	74.08
3	855	5	22	35.60	51.50	7.1	13.25
4	958	2	23	36.00	51.10	7.7	44.08
5	1119	12	10	36.38	50.00	6.5	148.55
6	1177	5		35.70	50.70	7.2	65.16
7	1301			36.10	53.20	6.7	166.70
8	1485	8	15	36.70	50.50	7.2	138.41
9	1495			34.50	50.50	5.9	160.70
10	1608	4	20	36.40	50.50	7.6	113.59
11	1665	6	15	35.70	52.10	6.5	61.54
12	1678	2	3	37.20	50.00	6.5	198.00
13	1687			36.30	52.60	6.5	125.50
14	1778	12	15	34.00	51.30	6.2	188.91
15	1808	12	16	36.40	50.30	5.9	115.00
16	1809			36.30	52.50	6.5	117.95
17	1825			36.10	52.60	6.7	115.40
18	1830	3	27	35.70	52.50	7.1	97.74
19	1868	8	1	34.90	52.50	6.4	132.38
20	1876	10	20	35.80	49.80	5.7	138.00
21	1935	4	11	36.36	53.32	6.8	186.24
22	1957	7	2	36.07	52.47	7.0	103.31
23	1962	9	1	35.71	49.81	7.2	145.70
24	1980	12	19	34.47	50.65	6.2	153.46
25	1990	1	20	35.90	52.97	6.0	141.85
26	1990	6	20	36.96	49.41	7.4	225.00
27	2002	6	22	35.85	48.94	6.5	220.00
28	2004	5	28	36.37	51.64	6.4	76.94

29	2007	6	18	34.54	50.91	5.9	150.00

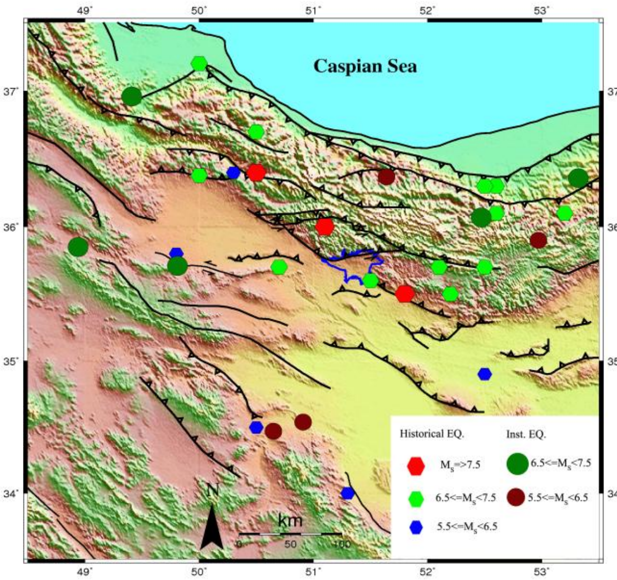


Fig. 3. Distribution of historical and instrumental earthquakes around Tehran city.

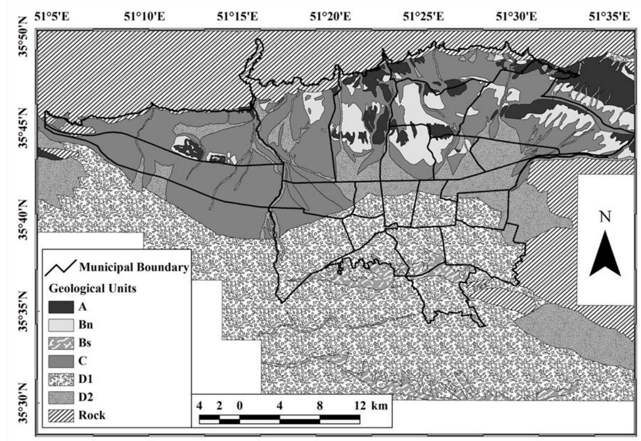


Fig. 4. Geological map of Tehran city.

Geology of Tehran

The area of study is limited by the Alborz, Sepayeh and Bibishahrbano Mountains in north, east and south-east, respectively. The area is divided into three structural and stratigraphic zones including northern mountains, eastern and south-eastern mountains, and Tehran plain. Rieben (1955) divided the Tehran Plain into six units as shown in Fig. 4.

The oldest alluvial deposits, A or Hezardarreh Formation, include conglomerates with a few lenses of sandstone, siltstone and mudstone, and are recognizable by regular stratification, relatively thin layers, and small clasts.

The B Formation is an unconformable layer that overlies eroded surfaces of the A Formation and includes two facieses: “Bn” (North Tehran inhomogeneous alluvial Formation) with conglomeratic mixture of gravel, pebble, and cobble-size clastics; and “Bs” (South Tehran clayey silt or Kahrizak Formation) with reddish brown and beige-colored clayey silt.

The C Formation includes homogenous conglomeratic young alluvial fan deposits, is composed of gray to brown colored gravel and pebble size clastics with silt and sand size matrix.

The D Formation (Recent Alluvium) is the youngest stratigraphic unit within Tehran region and is present as alluvial and fluvial deposits. This unit is subdivided into two different stratigraphic units, “D1” unit, as a veneer, covers the Bs Formation in the south and is composed of thin layer of greyish colored silt; “D2” unit with silty gravel, clastic size pebble is covered the C Formation in north.

METHOD OF ANALYSIS

Data processing

In an accurate seismic site effects assessment it is needed to clarify dynamic properties of the underlying layers and subsurface soils. Geophysical tests, are considered the most important techniques, are mainly used in evaluation dynamic properties of the underlying layers and estimation appropriate shear wave velocity profiles. However, based on projects importance and economic circumstance, sometimes it is essential to conduct an extended site effects assessment by using various geophysical techniques. In this study to achieve a reliable site effects assessment, series of detailed geotechnical and geophysical data were gathered. Most of these tests were conducted by national and local government’s corporations during recent year. Despite unequally distribution, these data cover most parts of the study area. The distribution of geotechnical and geophysical data is shown in Fig. 5. After processing all geotechnical and geophysical data, finally 20 sites which are categorized as C class and their shear wave velocity profile were reached to the defined seismic bedrock have been selected for site response analysis (Fig. 5). The selected sites had an accurate and detailed geotechnical and geophysical characteristics including soil type based on USCS, layer thickness, density, and shear wave velocity profile. For theoretical analysis the approximate site predominant period can be calculated by using this equation.

$$T_b=4H_b/V_S \tag{1}$$

where H_b is the total depth to the defined seismic bedrock and V_S is the average shear wave velocity given by:

$$V_S=\sum d_i/\sum d_i/V_{Si} \tag{2}$$

where d_i and V_{Si} are, respectively, thickness and shear-wave velocity of each layer up to H_b.

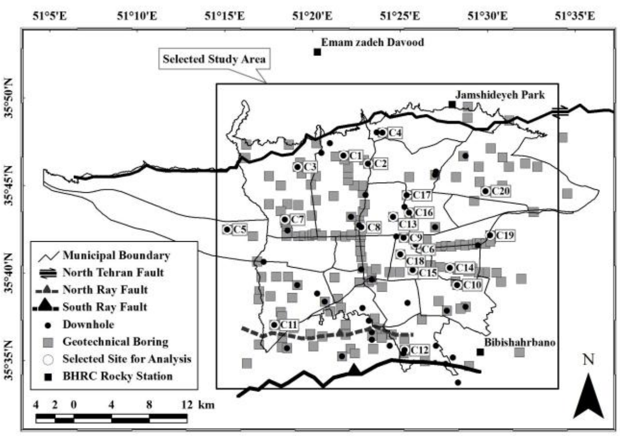


Fig. 5. Distribution of geotechnical and geophysical data in selected study area.

Seismic parameters analysis

The parameters of interest in site response analysis consist of the seismic bedrock properties, site predominant period, shear wave velocity in upper 30m, and peak bedrock acceleration. These parameters will be evaluated for Tehran city before site response analysis.

Seismic bedrock property. The depth to seismic bedrock was determined from geophysical test results. For this purpose, seismic bedrock has been defined as a rock-like media with shear wave velocity more than 750 m/s (Ishihara, 1982, UBC, 1997&2003, BSSC, 2003, and BHRC, 2005).

Site predominant period and shear wave velocity in upper 30m. The approximate site predominant period, T_b, can be calculated from equation (1). To clarify the class of site, average shear wave velocity was calculated in upper 30m. Therefore the relation suggested by NEHRP was used.

Peak bedrock acceleration (PBA). Different investigations have been carried out for the seismic hazard analysis of Tehran city (Berberian et al, 1993; Bozorgnia et al, 1982; Nowroozi et al, 1986; and Zare, 2005). In last study, seismic hazard analysis was carried out probabilistically by Zare (2005) and probabilistic peak bedrock acceleration (PBA) maps were published based on the attenuation relation developed by Ambraseys and Simpson (1991), Joyner, Boore and Fumal (1997), and Zare (1999, 2005). The PBA distribution maps were prepared for return periods of 75 (50% probability exceedance in 50 years), 475 (10% probability exceedance in 50 years), and 2475 (2% probability exceedance in 50 years) years. In Iranian Code (standard No. 2800 seismic design guide) the response spectrum for each class was suggested based on 475-year return period, therefore, in this study for comparison the calculated site response spectrum with those suggested in Iranian Code, the PBA distribution map for return period of 475-year was used for scaling selected bedrock motions.

SITE RESPONSE ANALYSIS

Equivalent-linear analysis was carried out to evaluate the response of each selected geotechnical and geophysical profiles to the scaled seismic bedrock motions. The characteristics of selected sites for site response analysis are shown in Table 2. The free EERA (Equivalent-linear Earthquake site Response Analysis) computer program (Bardet et al., 2000) was used for modelling the site as a one-dimensional system of horizontal, homogeneous and isotropic soil layers. Due to lack of cyclic tests, the well-known shear modulus-strain and damping ratio-strain relations proposed by Seed and Idriss (1970) for sand and clays were used in analyses. For input motion the recorded bedrock motions in BHRC acceleration stations in Tehran city were used as bedrock input motion. These motions were recorded during Firozabad-Kojour (2004) earthquake, which occurred near (70 km) Tehran city. The following three records at rocky stations were used for this purpose: Emam zadeh Davood (EMD), Jamshideyeh Park (JAP) and Bibishahrbano (BSH) (Fig. 5). The recorded time history in these rocky stations is shown in Fig. 6. Next, all three acceleration time histories were normalized to the 475-year PBA. Then for each site, the results in term of site response spectrum, considering 5% critical damping, and site amplification factor, in period ranges 0.1- 0.5 and 0.1- 2.5 s, were computed by subjecting their representative geotechnical and geophysical profiles to the normalized 475-year bedrock input motions. The evaluation of amplification factor in range of period 0.1–0.5s can be considered representative of the dominant period of typical buildings of the area and the amplification factor in range of period 0.1–2.5 s can be considered representative of the dominant period of generic buildings.

Table 2. Characteristics of selected sites in site response analysis (H_b: Depth to defined seismic bedrock, V_{Sb}: The average value of V_S in upper seismic bedrock, T_b: Site predominant period, V_{S30}: The average value of V_S in upper 30m)

Site ID	H_b(m)	V_{Sb}(m/s)	T_b(s)	V_{S30}(m/s)
C1	38	594	0.256	553
C2	16	531	0.121	642
C3	20	510	0.157	597
C4	7	509	0.055	724
C5	22	584	0.151	655
C6	44	568	0.310	504
C7	24	439	0.219	480
C8	34	476	0.286	455
C9	32	555	0.231	552

Table 2. Continued

Site ID	H_b(m)	V_{Sb}(m/s)	T_b(s)	V_{S30}(m/s)
C10	20	490	0.163	622
C11	40	413	0.387	422
C12	24	375	0.256	424
C13	35	560	0.250	537
C14	34	604	0.225	585
C15	36	494	0.291	450
C16	23	611	0.151	654
C17	26	652	0.160	669
C18	30	601	0.200	601
C19	12	416	0.115	665
C20	16	399	0.160	538

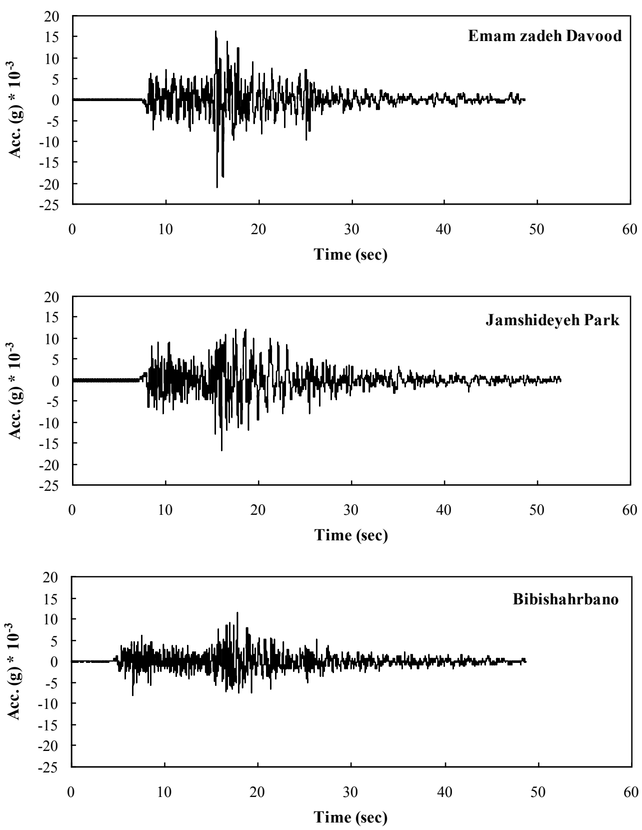


Fig. 6. Recorded time histories in rocky stations.

RESULTS AND DISCUSION

The results of site response analysis in term of site response spectrum and site amplification factor for selected sites are given in Fig. 7 and 8, respectively. For each site the average of site response spectrum and site amplification factor are presented. The estimated response spectra for site class C were compared with the standard response spectrum for site class C, presented in Iranian Code (Standard No. 2800). In this Code the curves for response spectrum were estimated based on several parameters including the average shear wave velocity in upper 30m, soil type and seismic vulnerability of desired area. The comparison between the estimated response spectra and the suggested one in Iranian Code reveals that the estimated one has lower value than the standard response spectrum, but their trend seem to be similar. The smoothed curve for site class C is presented in Fig. 9. Since there are a few earthquake data and analyzed sites, it is difficult to give engineering judgment about the reliable response spectrum. Also, the presented values for amplification factor in ranges of period 0.1–0.5s and 0.1–2.5 s can be used in designing typical and generic buildings in area.

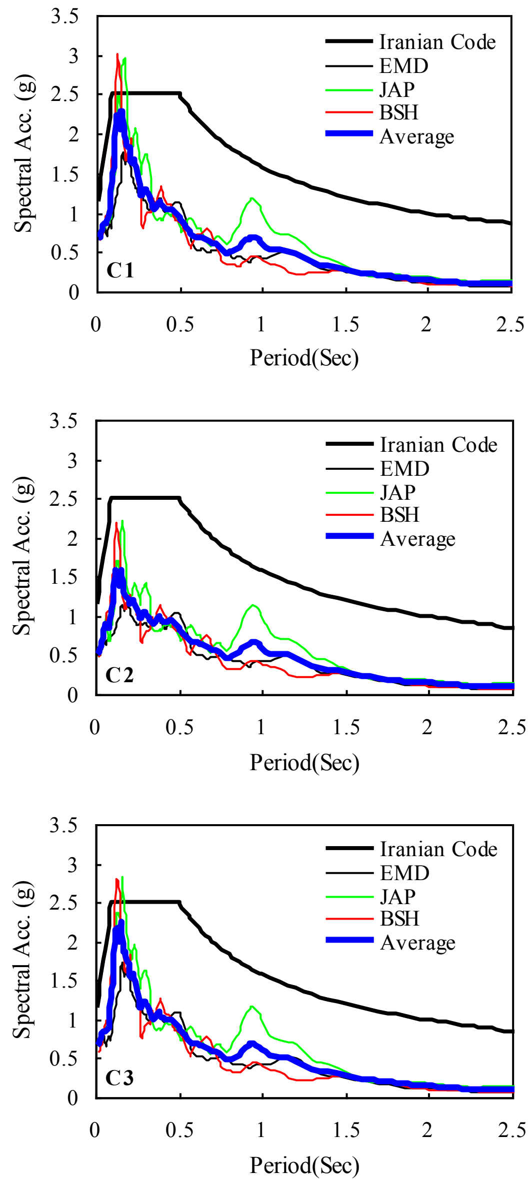
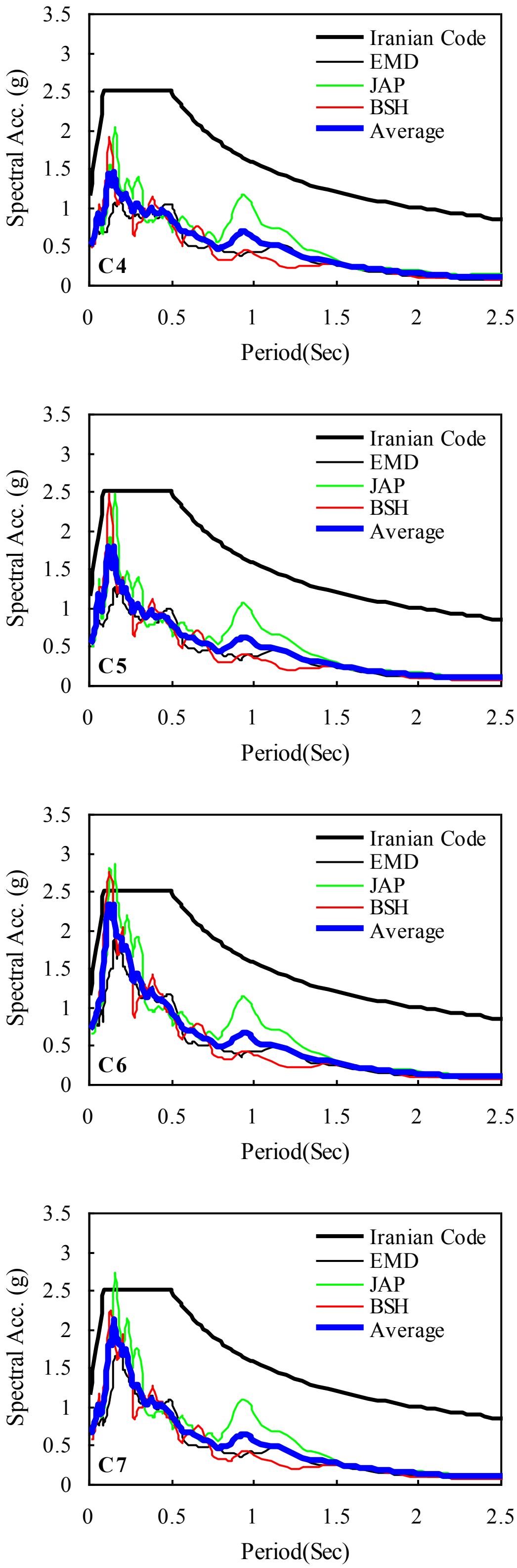


Fig.7. Site response spectrum for analyzed sites.



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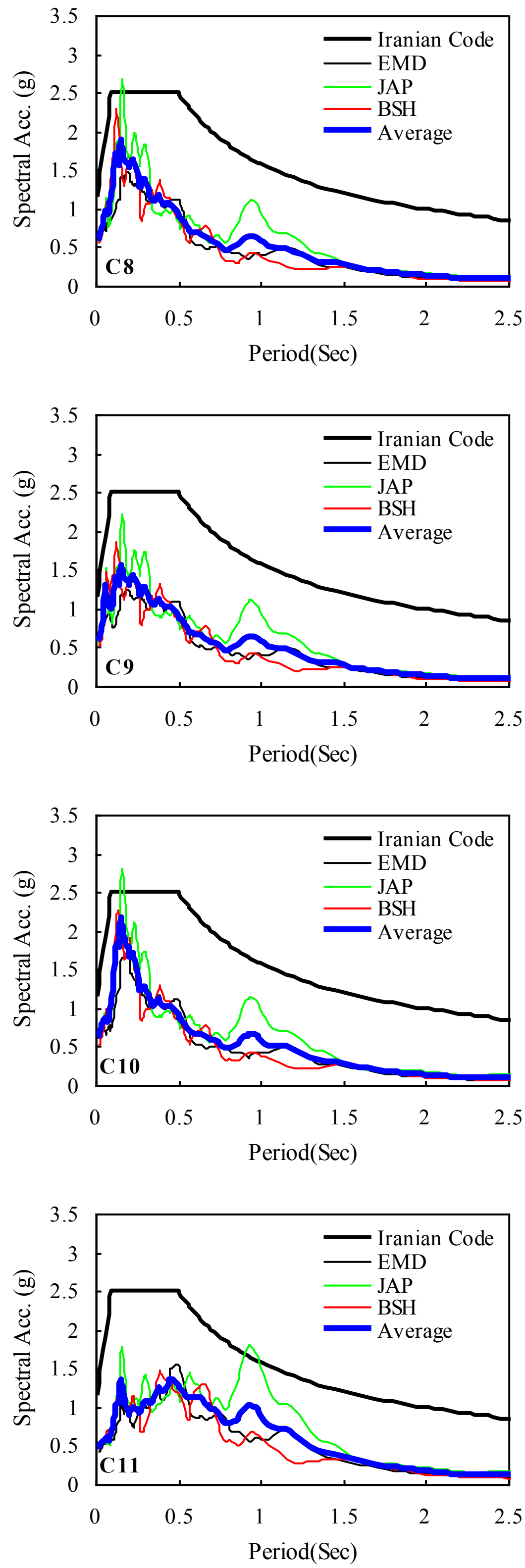

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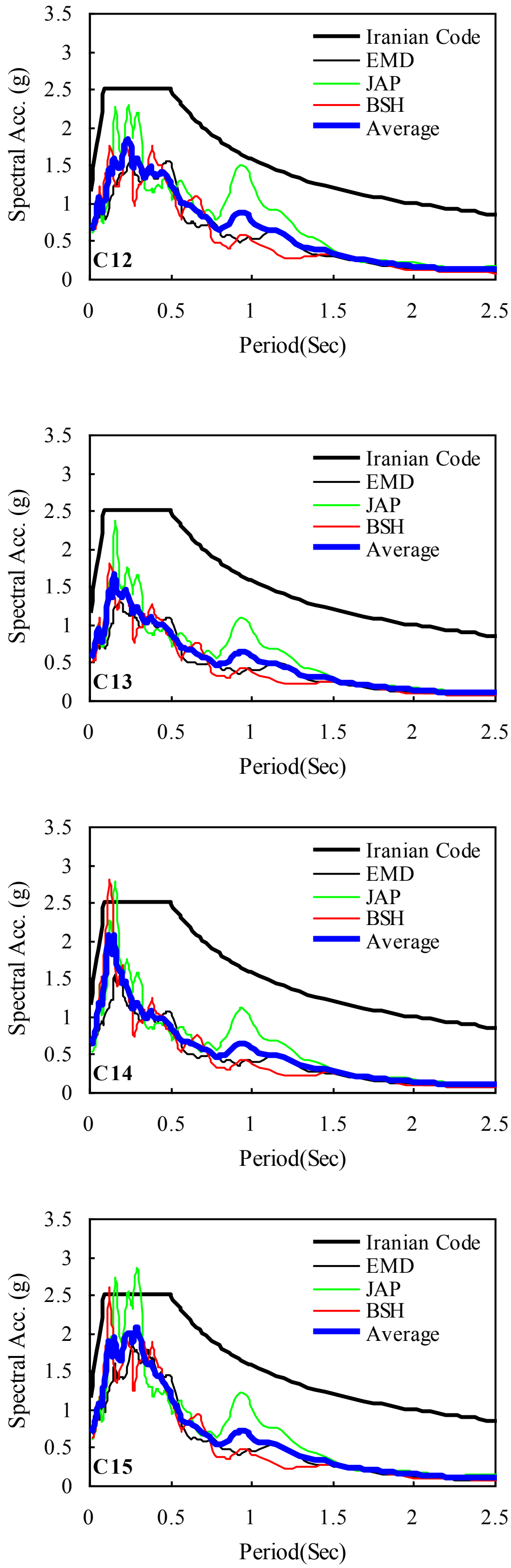

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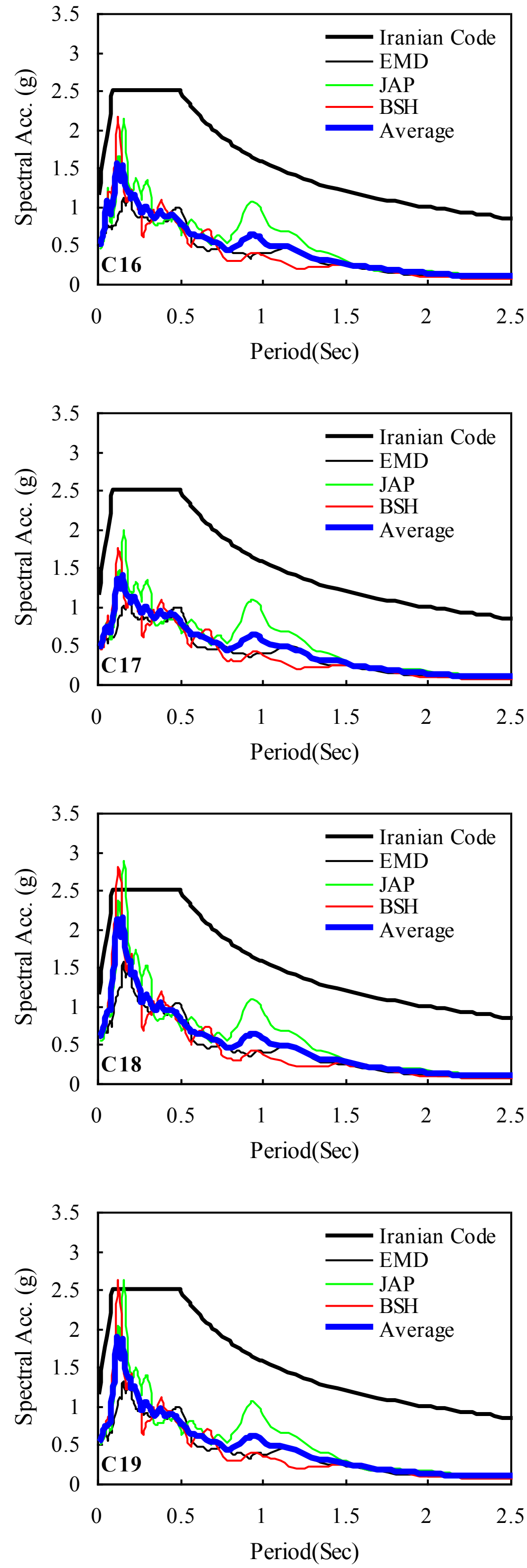

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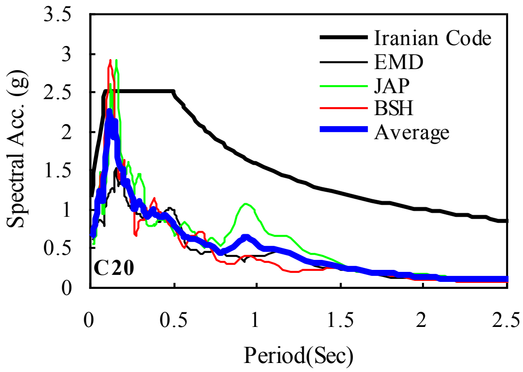

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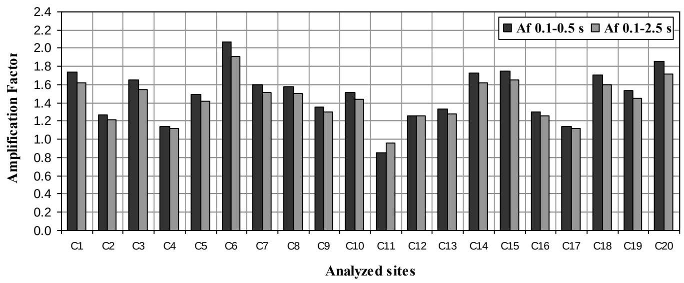

Fig. 8. Values of the amplification factor (Af) for Analyzed sites.

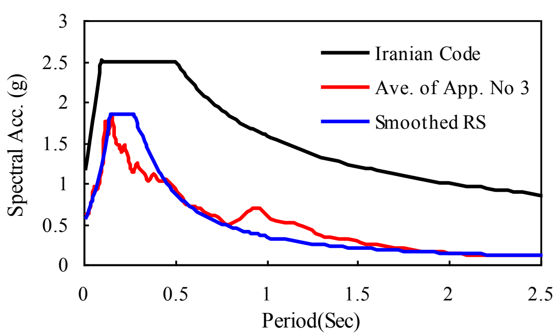

Fig. 9. The smoothed curve for site class C.

CONCLUSION

This paper presents the most important features of site effects assessment studies for Tehran city. Evaluations of site characteristics were performed based on geotechnical and geophysical data. The recorded bedrock motions were used as bedrock input motion. One-dimensional equivalent-linear site response analyses were performed for the selected profiles representing the geotechnical and geophysical characteristics of the study area. All analyzed sites were categorized as C class based on class assigned way by NEHRP. Based on equivalent-linear analysis, the response spectrum and site amplification factor in two ranges of period (0.1-0.5 s and 0.1-2.5 s) were calculated for each site. The estimated site response spectra were compared with the suggested one in Iranian Code. This comparison reveals that there are acceptable trend between the estimated response spectra and Iranian one. Since there are a few data, it is difficult to give a reliable engineering judgment about the estimated response spectra. The values of amplification factor in ranges of period 0.1–0.5s and 0.1–2.5 s can be considered in designing typical and generic buildings of the area.

REFERENCES

Kramer, S.L. [1996]. "*Geotechnical earthquake engineering*". Prentice-Hall Inc., Upper Saddle River, New Jersey.

Hessami, K., Jamali, F. and Tabassi, H. [2003]. "*Map of Major Active Faults of Iran*". Bulletin of International Institute of Earthquake Engineering and Seismology.

Ambraseys, N.N. and Melville, C.P. [1982]. "*A History of Persian Earthquakes*". Cambridge University Press, U.K.

Rieben, E.H. [1955]. "*The geology of the Tehran plain*". American Journal of Science 253, 617-639.

Ghayamghamian, M.R. and Nojavan, A.R. [2008]. "*A new site classification system based on strong motion analysis in Iran*". GSP NO.181, ASCE.

Ishihara, K. and Ansal, A.M. [1982]. "*Dynamic behavior of soil, soil amplification and soil structure interaction*". Final Report for Working Group D, UNDP/ UNESCO Project on Earthquake Risk Reduction in the Balkan Region.

International Council of Building Officials. [1997]. "*Uniform Building Code*".

International Council of Building Officials. [2003]. "*International Building Code*".

Building Seismic Safety Council. [2003]. "*NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*". Part 1: Provisions (FEMA 368).

Building and Housing Research Center. [2005]. "*Iranian Code of Practice for Seismic Resistant Design of Buildings*". Standard No.2800, 3rd Ed.

Berberian, M., Qoreyshi, M., Arzhang-ravesh, B. and Mohajer-Ashjai, A. [1993]. "*Recent tectonics, seismotectonics and earthquake-fault hazard study of the greater Tehran area*". Contribution to the seismotectonics of Iran, part V, Geological Survey of Iran; Rep. No. 56.

Bozorgnia, Y. and Mohajer-Ashjai, A. [1982]. "*Seismic risk investigation of major cities of Iran*". Journal of the Earth and Space Physics 11, 15–38.

Nowroozi, A. A. and Ahmadi, G. [1986]. "*Analysis of earthquake risk in Iran based on seismotectonic provinces*". Tectonophysics 122, 89-114.

Zare, M. [2005]. "*Seismic hazard analysis in greater Tehran area (in Farsi)".* Final Report for International Institute of Earthquake Engineering and Seismology.

Berberian, M. [1995]. "*Natural hazards and the first earthquake catalogue of Iran*". Vol. 1. Historical Hazards in Iran prior to 1900. A UNESCO/IIEES publication during UN/IDNDR-IIEES.

Berberian, M. and Yeats, R.S. [1999]. "*Patterns of historical earthquake rupture in the Iranian Plateau*". Bulletin of the Seismological Society of America 89, 120–139.

Martini, P.M., Hessami, K., Pantosti, D., D'Addezio, G. and Alinaghi, H. [1998]. "*The geologic contribution to the evaluation of the seismic potential of the Kahrizak fault (Tehran, Iran)*". Tectonophysics 287, 187–199.

Bardet, J.P., Ichii, K. and Lin, CH. [2000]. "*EERA: A computer program for Equivalent-linear Earthquake site Response Analyses of layered soil deposits*". Department of Civil Engineering, University of Southern California, Los Angeles, California.

Seed, H.B. and Idriss, I.M. [1970]. "*Soil Module and Damping Factors for Dynamic Response Analysis*". Report EERC 70-10, Earthquake Engineering Research Center, University of California, Berkeley.

Building and Housing Research Center. Iran Strong Motion Database. http://www.bhrc.ac.ir/index.html.